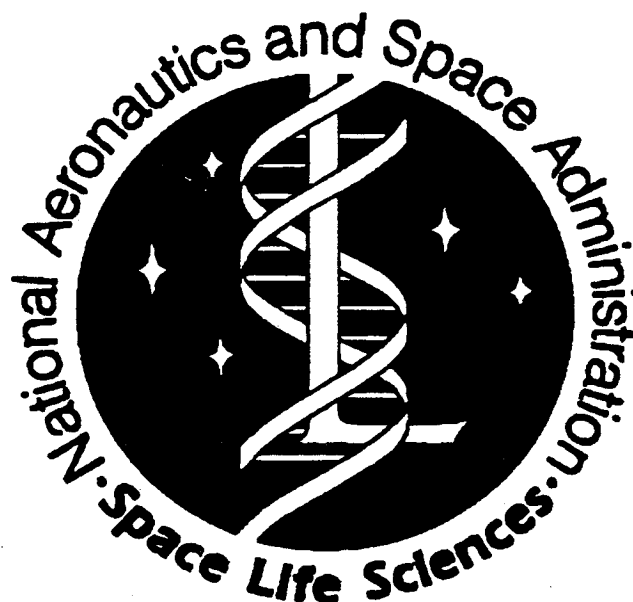


SPACE HUMAN FACTORS DISCIPLINE SCIENCE PLAN

1991



**SPACE HUMAN FACTORS PROGRAM
LIFE SCIENCES DIVISION
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
WASHINGTON, D.C.**

(NASA-TM-108023) SPACE HUMAN
FACTORS DISCIPLINE SCIENCE PLAN
(NASA) 18 p

N93-21370

Unclass

G3/54 0151043

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1.0 INTRODUCTION

In a major policy speech on July 20, 1989, the President proposed that the United States commit to a sustained program working toward a manned presence in space, human exploration of the solar system, and the permanent settlement of space. This plan entails making Space Station Freedom operational, returning to the Moon on a permanent basis, and conducting human exploration missions to Mars. All of these missions present crucial challenges for the life sciences research and technology development programs, particularly in the discipline areas of behavior, performance, and human factors, and will provide research opportunities in the collection of space flight data in this discipline.

NASA's planned exploration missions will involve sending small crews into space for extended periods. The programs and periods include the Extended Duration Orbiter, up to 28 days; Space Station Freedom, up to 6 months; and the Exploration missions, including a lunar outpost, a Mars expedition, and a Mars outpost, up to 3 years. These missions require a thorough understanding of behavioral adaptation to space, and of the conditions that support and enhance human capabilities for living and working productively for prolonged periods in extremely isolated, confined and dangerous environments. A thorough understanding of behavioral responses in space is necessary in order to design environments and develop countermeasures and support systems that protect and enhance human capabilities, safety, health, and productivity. Specific requirements are derived from the Space Human Factors discipline within the Biomedical Programs of the Life Sciences Division. The research in this discipline reflects a multifaceted approach to understanding basic human capabilities in space environments, including psychological, social, environmental, perceptual, and behavioral aspects, as well as human-machine interfaces and habitability.

1.1 PURPOSE

The purpose of this Discipline Science Plan is to provide a conceptual strategy for NASA's Life Sciences Division research and development activities in the comprehensive areas of behavior, performance, and human factors. This document summarizes the current status of the program, outlines available knowledge, establishes goals and objectives, defines critical questions in the subdiscipline areas, and identifies technological priorities. It covers the significant research areas critical to NASA's programmatic requirements for the Extended Duration Orbiter, Space Station Freedom, and Exploration mission science activities. These science activities include ground-based and flight; basic, applied and operational; and animal and human research and development. This document contains a general plan that will be used by both NASA Headquarters program offices and the field centers to review and plan basic, applied, and operational research and development activities, both intramural and extramural, in this area.

1.2 BRIEF DESCRIPTION OF THE DISCIPLINE

The NASA Life Sciences Division has integrated all research and development activities involving behavior, performance, and human factors under the program of Space Human Factors. This program represents a multi-faceted research field that encompasses basic and applied questions regarding behavioral capabilities and responses in reduced-gravity environments. The discipline includes psychophysiological, experimental, behavioral, systems design, sociological, personality, and psychiatric methodological approaches to studying the issues. NASA's mission and programmatic requirements involve understanding the underlying parameters of behavioral adaptation to microgravity and other aspects of the space environment, as well as the human dynamics of that environment. The research activities in this discipline include determining the specific behavioral responses to microgravity exposure and space flight, the dynamics involved in living and working in the space environment, and how these factors affect operational and design requirements of the spacecraft.

The human in space is subjected to a multitude of factors that may affect physiological and psychological well-being, crew interactions, and successful performance of mission-related duties. Some of these factors are unique to the space environment (e.g., prolonged periods of microgravity), while others are also present in special work environments (e.g., confinement, relative isolation, hazards, altered work/rest schedules). This area of research seeks to identify, define, and describe the factors that affect behavior and performance in space. The approach includes the study of both the acute and chronic effects of prolonged periods of living and working in space on behavioral, psychological, and performance responses. The approach incorporates an understanding of the time course and magnitude of the changes that occur; identifies the salient and critical variables and their underlying mechanisms of action; and develops standards, requirements, protocols, and effective countermeasures to ensure crewmembers' safety, well-being, and productivity, along with mission success.

2.0 BACKGROUND AND CURRENT KNOWLEDGE

2.1 BRIEF HISTORY OF THE DISCIPLINE AS PART OF LIFE SCIENCES

During the early days of the United States manned space flight program, the primary life sciences concerns were focused on determining the physical needs of astronauts, in particular, operational and biomedical support of the crews in areas such as radiation exposure and physiological effects of microgravity. In contrast, very little attention was focused on behavioral adaptation to reduced gravity or on crews' psychological or social adjustment to space flight. As space flight mission durations increased, especially with Skylab, more emphasis was placed on human factors concerns, although the emphasis was primarily on habitability concerns.

There is an extensive and comprehensive scientific knowledge base available that relates to space human factors. The base includes a core of ground-based and aviation research and technology, as well as data from isolated and confined

environments including undersea habitats, submarines, and polar stations. However, specific applied and operational ground-based data need to be developed and validated for the space environment.

Existing space-based data in this area are sparse, limited, and anecdotal. The specific effects of the space environment on behavioral processes and human performance have not been investigated in any systematic way. Actual data on space flight experience is sparse, and the anecdotal nature of the information currently available makes the data difficult to evaluate. Behavioral scientists have had little or no direct access to flight and ground crews, which has resulted in a lack of systematic assessment of individual performance both in training and during missions. The absence of such data makes it difficult to identify and evaluate factors that may influence human performance. Space-crew factors and performance need to be qualitatively and quantitatively studied in depth before human planetary exploration and a lunar base mission are undertaken.

2.2 CURRENT KNOWLEDGE BASE

Human factors experiments during short-duration (10-day) space flights have concentrated on the effects of the space environment on physical performance criteria, especially sensory-motor disturbances, visual function, illusions, and proprioception. Most of the published accounts of manned space missions suggest that, with few exceptions, decrements in performance have usually been transient, occurring early in the mission. Some spatial and proprioceptive illusions have been reported by astronauts. Other reflexes have been found to be slightly impaired early in flight, followed by adaptation. Further illusions and reflex impairment have been observed immediately upon returning to Earth's gravity. Mass discrimination ability is impaired as well. Yet, these changes, to the extent they occur, have not been sufficient to interfere with mission completion for these short-duration flights. Many of the problems experienced can be related to the learning of new perceptual and motor skills in weightlessness, as well as to the spatial disorientation and space sickness that occur early in a mission. There have been a number of contradictory reports on visual function; however, there have been no instances of an alteration in visual function having a negative impact on overall mission success. In conclusion, the evidence gathered during short-duration space missions indicates that behavioral capabilities can be maintained during space flights, despite some small decrease in work capacity early in flight. However, there is no data base for longer durations, limiting the applicability of current knowledge to future long-duration exploration missions and lunar base establishment.

Anecdotal evidence indicates that astronauts have experienced performance decrements in the form of experimental errors, lost data, and equipment mishandling during space flight. Some inflight evaluation of cursor control devices has been performed on Shuttle flights to identify the design that is most effective to use in space. Evaluations of computer display devices on the Space Shuttle have shown the electroluminescent computer display to be superior to the liquid crystal display.

A number of human factors studies have investigated the relation between sleep and performance during space flight. Poor sleep quality and fatigue have been reported on a number of missions. About thirty percent of U.S. Shuttle astronauts have requested

sleep medication inflight, although none had a history of usage on Earth. During the Soyuz program, when sleep schedules were set counter to the local time of the launch site, cosmonauts experienced some degradation of performance and disturbed sleep.

With regard to spacecraft habitability, there have been reports that noise levels are high and unpleasant odors abound. Anecdotal and observational data have revealed that on STS missions, the crew perceives that the living space is confined, food is restricted in quality and diversity, privacy is lacking, and facilities for personal hygiene are limited. Some human factors data were collected onboard each of the three Skylab missions. Information was obtained on several aspects of living in space, including: environment, architecture, mobility and restraint of crewmembers, food and drink, garments, personal hygiene, housekeeping, communication, and off-duty activities. In addition, data were gathered to understand the crew's capability to perform work in microgravity during long-duration space missions.

Crew dynamics have been primarily studied using observational and anecdotal data from both U.S. and Soviet space missions. A list of behavioral dysfunctions has been compiled from these data, including fatigue, irritability, depression, anxiety, mood fluctuations, boredom, tension, social withdrawal, and motivational changes. Instances of interpersonal hostility have been reported between crewmembers, and between space and ground crews during flight. These problems are more frequent with heterogeneous crews, and problems have resulted from misunderstood communications in crews where there were language difficulties. However, despite these anecdotes of interpersonal problems, no conflict of this nature has ever been known to affect the success of a mission. There is also limited information available from astronauts and cosmonauts on some group dynamics issues such as crew size and leadership style. Cosmonauts have stated that they prefer a shared leadership style and want to have some input into their duties.

3.0 DISCIPLINE GOALS, OBJECTIVES, AND CRITICAL QUESTIONS

3.1 GOALS

The overall goals of the space human factors discipline are:

- Understand the psychological, behavioral, and performance adaptation to space
- Develop procedures and protocols for ensuring crewmembers' well-being, safety, and productivity in space.

3.2 OBJECTIVES

The objectives of the discipline are as follows:

- Determine the acute and long-term psychological, behavioral, and performance responses to space

- Determine the critical factors that affect behavior and performance in space and understand the underlying mechanisms
- Determine the human factors and habitability requirements for space flight
- Develop and evaluate design requirements, monitoring techniques, and procedures
- Develop and verify ground-based models and analogs to study these responses.

Over the past 20 years, numerous reports related to NASA's needs in the space human factors discipline have been published. These reports have emphasized major goals and objectives relative to this discipline and have remained fairly broad and top-level. Three reports on strategies for life sciences research have emphasized the crucial role of human factors research related to space-flight missions, present and future. In "A Strategy for Space Biology and Medical Science for the 1980's and 1990's," it was noted by the Committee on Space Biology and Medicine (Goldberg) that behavioral and psychological problems were more likely to occur during longer and more diverse missions, and should be better understood. Another report, "Exploring the Living Universe: A Strategy for Space Life Sciences," by the NASA Life Sciences Strategic Planning Study Committee (Robbins), also emphasized behavioral questions, including crew/environment interactions, human-machine interactions, crew selection, command and control structure, and crew motivation. Recommended strategies for researching these topics included ground-based simulations and analogs. Another report developed by the Federation of American Societies for Experimental Biology (FASEB) also delineated the factors that influence the behavior and performance of space crews including psychological, social, environmental, and systems design factors. The present Discipline Science Plan incorporates recommendations from the Goldberg, Robbins, and FASEB reports.

3.3 CRITICAL QUESTIONS

3.3.1 Crew and Team Factors (in priority order)

1. What are the group characteristics and processes that influence crew compatibility, capability, satisfaction, and productivity during space flights of increasing duration involving various space vehicles and mission requirements (e.g., size, composition, skill mix, demographics, and cultural background)?
2. What are the major human factors principles that govern optimal assignment of responsibilities between space crews and ground teams and among crew and team members? What ground-based organizations and systems are required for effective support of flight crew performance on the planned missions?

3. What are the critical elements and processes involved in decision making by ground teams and space crews operating autonomously or in combination?
4. What are the critical characteristics and functions of leaders that help crews meet objectives and sustain satisfaction, high morale, and productivity during various missions?
5. What are the optimal crew command structures for various space missions?
6. What are the optimal communication processes for coordination among crewmembers and between ground and space crews?

3.3.2 Selection and Training (in priority order)

1. What behavioral and psychometric criteria should be used for selecting the best candidates for long-duration missions? What criteria should be adopted for composing the optimal crew mix for particular missions of varying durations?
2. What are the preferred protocols for training effective ground teams and space crews in problem solving, enhanced communication, crew coordination, and interpersonal dynamics?
3. What training for job skills should be accomplished on the ground? In space? What are the requirements for on-board training? How will the effectiveness of training be measured?

3.3.3 Habitability (in priority order)

1. What are the requirements for adequate quality of life as they relate to food, clothing, hygiene, vibroacoustics, lighting, and personal needs in spacecraft and habitats?
2. What are the optimal designs for living/working areas in spacecraft/habitats to enhance morale and performance?
3. What are the privacy requirements for individual crewmembers, as well as the crew as a whole in relation to outside observers?
4. What facilities and activities are required for crew off-duty periods?

3.3.4 Human-Machine Interaction (in priority order)

1. What are the factors involved in integrating automated systems with human capabilities to promote productivity and reliability? What are the significant issues of control and intervention by human operators, and how should these be resolved for particular missions?

2. What factors should be considered (e.g., maintainability, reliability, operator discretion) when allocating functions between humans and machines?
3. What are the physical performance capabilities of humans in different stages of space flight as a function of mission parameters (e.g., duration, gravity field, physical environment)? What assist devices will be required at each stage?
4. What are the anthropometric requirements for work stations to enhance individual team member performance?
5. What are the mission-specific design requirements for telecommunications to optimize crew performance?
6. What are the requirements for formatting, distributing, managing, accessing, updating, and presenting information for optimal individual and crew performance? What are the requirements for crew input to the data management system?
7. How can artificial intelligence systems be used to support human decision making in long-duration space flight?
8. What are the significant human factors issues in teleoperation?

3.3.5 Behavioral Processes (in priority order)

1. What are the effects of living in the space environment on cognitive functions (including attention, memory, information processing and decision making) and on work capacity?
2. How do the fundamental behavioral processes of perception and sensation, learning and cognition, and motor skills change in space? What is the time course of adaptation?
3. What are the behavioral correlates of physiological changes induced by the space environment?

3.3.6 Performance Capabilities (in priority order)

1. What are the critical performance capabilities that are mission-relevant and likely to be affected by space exploration (e.g., cognitive, perceptual-motor, higher-level decision making)?
2. What procedures are available and preferable for analyzing missions for their demands on human performance (e.g., task analytical techniques and models)?

3. How is workload optimized for various space exploration missions?
4. What are the criteria for evaluating individual and crew performance and productivity during space missions of various durations?
5. What are the most effective schedules for work, rest and recreation, exercise and sleep for enhancing human performance and adaptation during long-duration exposure to space?
6. What are the special performance requirements and capabilities and equipment requirements for extravehicular activity (EVA)?
7. What minimally intrusive hardware and software capabilities are best suited for obtaining performance data inflight?
8. What models can be developed to describe the effects of fundamental behavioral processes on mission performance?
9. How do circadian rhythm cycles and sleep disruption influence performance and interact with the space environment to affect ability to accomplish mission goals? What countermeasures (e.g., pharmacology, lighting, etc.) can be developed to improve performance and productivity?
10. What are the acute and long-term effects of the space environment on sleep architecture, quantity, and quality?
11. In what way do space-induced physiological changes affect task performance? What are the best psychophysiological correlates of effective performance in the space environment?

3.3.7 Stress/Crew Support Systems (in priority order)

1. What are the effects of stress on crew and ground team performance and what detection and intervention strategies (e.g., selection, training, crew support) prove effective in ameliorating any negative impacts?
2. What are the factors that shape individual and team motivation and the ability to cope effectively with environmental stress?
3. What procedures should be developed for determining and maintaining individual and team psychological health?
4. How does one characterize the process of individual and team adaptation to stressors (e.g., isolation, confinement, and risk) inherent in space flight?

4.0 TECHNOLOGY

New or refined tools and techniques need to be developed in order to understand human performance in space flight. Performance assessment techniques and systems to measure the effectiveness of groups are needed. Techniques to analyze human-machine interactions, including anthropometrics and biomechanics measures and human-computer interaction and human-robot interaction evaluation tools, also need to be developed. In addition, selection and training systems need to be designed. New and refined or second-generation technologies that address these needs are listed, in priority, below.

4.1 NEW TECHNOLOGY

- Technologies for inflight evaluation of cognitive workload and strategic behavior
- Hardware and software for embedded training evaluation inflight
- Anthropometric and biomechanics inflight measuring systems
- Multi-purpose human performance measurement tools for inflight testing (both intrusive and non-intrusive)
- Behavior measurement systems of individuals and teams for inflight use
- Voice recorder that is minimally intrusive, small, lightweight, and high performance, having large storage capability in a small volume
- Integrated, ground-based simulation system that recreates applicable physical and functional characteristics, all of which can be varied to evaluate situations on Space Station Freedom, lunar base, and Mars missions
- Technologies that evaluate and enhance human interaction with intelligent machines that learn
- Computer simulations of teleoperation in space to be used for ground study
- Evaluation techniques for measurement of effectiveness of human communication and advisory systems
- Psychomotor measurement tool for inflight testing (e.g., 2 or 3 degrees-of-freedom hand controller)
- Hardware and software to provide space human factors standards and guidelines to engineers and operations personnel in a multimedia fashion

- Technologies to enhance visualization, understanding and management of science data
- Hardware and software for behavior and performance measurements in space analog environments
- Clothing design and maintenance
- Automated speech-to-text transcription of voice communications
- Synthetic task analytical workstation to functionally represent job requirements.

4.2 REFINED TECHNOLOGY

- A flight-certified, lap-top computer system that can be used to:
 1. Support multiple, concurrent tasks (both cognitive and psychomotor)
 2. Measure unstable tracking variables of response delays, tracking gain, and remnants
 3. Network many computers together to examine computer-supported group work among the crew and with the ground support personnel
- Astronaut selection, classification, and training criteria and assessment for fitness-for-duty
- Integrated task analysis methodology for workload timelines
- Development of an inflight video system capable of motion and time analysis
- Video and audio technologies to study communication in analog and space-flight environments relative to crew resource management
- Technologies for modeling and simulating human cognitive performance of space and ground crews
- Technologies that evaluate and enhance human interaction with intelligent machines
- Virtual reality for low cost/low mass simulation for enroute training
- Improved anthropometric and biomechanics measuring systems for ground use (e.g., Laser Anthropometrics Measurement System - LAMS)
- Development of software for inflight crew debriefing

- Multi-channel physiologic monitoring system, including EEG, EOG, EMG, EKG, and evoked potentials.

5.0 RESEARCH STRATEGY

The Space Human Factors research area priorities for each of the NASA mission eras are presented in Table 1.

Table 1

SPACE HUMAN FACTORS	STS ERA	SPACE STATION ERA	EXPLORATION ERA
BEHAVIORAL PROCESSES	6	6.5	7
PERFORMANCE CAPABILITIES	1.5	4	4.5
STRESS/CREW SUPPORT SYSTEMS	7	6.5	3
CREW FACTORS	4	2.5	1.5
HABITABILITY	5	5	6
HUMAN-MACHINE INTERACTION	1.5	2.5	1.5
SELECTION AND TRAINING	3	1	4.5

Space Human Factors research needs to be accomplished by a combination of ground-based and flight studies. Ground-based studies should build on the existing knowledge base and develop comprehensive space human factors information through laboratory, modeling, simulation and analog studies. Comprehensive literature reviews of the existing data should be conducted, and an integrated computer data system should be developed.

In addition, in order to develop a substantial core of knowledge in this area, the Discipline Working Group urges the establishment of a NASA Specialized Center for Research and Training (NSCORT) in Space Human Factors. This significant, ground-based extramural research initiative should be designed to advance basic knowledge and generate effective strategies for solving specific problems within space psychology and human factors, and to expand the pool of scientists and engineers dedicated to supporting future human factors research for space exploration.

Useful models can be developed for a variety of space human factors elements, including individual and group performance, workspace configuration, and habitability parameters. Human-machine interaction, operational parameters and habitability issues can also be studied using systems development techniques and computer

simulations, such as PLAID (Panel Layout Automated Interactive Design) and SAINT (Systems Analysis of Integrated Network Tasks).

Ground-based research should also involve the use of simulation facilities such as the KC-135 test aircraft, the Weightless Environment Test Facility (WETF), and the Advanced Cab and 727 cockpit simulators. The KC-135 test aircraft provides 30-35 seconds of microgravity during parabolic maneuvers, and is especially suited for short-duration tasks that can involve gross and fine motor manipulations, as well as technology concept validations. The WETF is a neutral buoyancy facility that simulates the microgravity environment and is applicable to studies of human performance during extravehicular activity. Both the Advanced Cab (generic glass cockpit) and full-motion 727 cockpit simulators are useful in examining a range of crew communication and coordination issues and human-automation issues.

Research should be conducted in ground-based analogs in order to identify key crew parameters and to use these analogs as testbeds for protocols and countermeasures. Ground-based analogs that have been identified as particularly relevant to space are submarines, undersea habitats, and the polar regions. These analogs offer special advantages, including 1) remote, confined, isolated and potentially hazardous environments in which a variety of crew factors and small group dynamics can be studied and 2) a subject population engaged in real and important work, whose behavior and performance can be observed and measured in the context of the total environment. Research in nuclear submarines and undersea habitats, resembling experience in space transportation vehicles or space station, can be used to understand crew issues, telecommunications, and space allocation needs in confined environments. Research in both the arctic and the antarctic regions can be used to examine small group dynamics, selection characteristics, and stress-coping mechanisms in remote environments. In addition, national and international research cooperation in analog environments should be developed to optimize resources and maximize the human factors data collected. Joint research activities should be pursued with international space agencies (e.g., CNES, ESA), as well as national agencies (e.g., the National Science Foundation [polar regions] and the National Oceanic and Atmospheric Administration [undersea habitats]).

The availability of flight data in human factors research is very limited, so space-flight research opportunities on the Space Shuttle and eventually Space Station Freedom are critical in order to collect systematic data and develop and validate procedures, protocols and techniques for human space exploration. At present, missions on the Space Shuttle are up to 9 days long, increasing to a maximum of 16 days in the mid 1990's. Space Station Freedom will have missions of up to 16 days during man tended capability (MTC) and up to 180 days during permanent manned capability (PMC). With the increasing length of the missions, more of the psychological, behavioral, and performance effects of space flight will be able to be investigated. In fact, some of the requirements and countermeasures for ensuring crewmember well-being, safety, and productivity can only be investigated on the longer Shuttle and Space Station missions.

It is crucial that several planned Spacelab missions devoted to the study of behavior and performance be conducted. These include the International Microgravity

Laboratory-2 (IML-2) Spacelab, in which the effects of flight on human cognitive processes, perceptual-motor performance, sleep and circadian rhythms will be systematically investigated. In conjunction with this flight, joint research activities with the German Space Agency, DARA, in human performance will be pursued. NASA also needs to continue to develop plans for Neurolab, a Spacelab mission dedicated to neuroscience and "state of the art" brain and behavior research.

Comprehensive and systematic data on basic behavioral changes in microgravity, including attention, memory, perception, psychomotor performance, etc., may be best collected with nonhuman primates. The use of animal models for studying human behavior and performance processes in laboratories has been validated, and there is a substantial body of ground-based data collected for purposes of comparison. To take advantage of animal models and the significant data that can be collected with them, it is important that behavioral studies using rhesus monkeys, which have been planned as part of a joint NASA/CNES research activity for Spacelabs in the 1990's, be completed.

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